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Review on load frequency control for power system stability

Muhammad Nizam Kamarudin[1], Nabilah Shaharudin[2], Noor Haqkimi Abd Rahman[3], Mohd Hendra Hairi[4], Sahazati Md. Rozali[5], Tole Sutikno[6]
[1,2,4]Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, Malaysia
[3]School of Electrical Systems Engineering, Universiti Malaysia Perlis, Malaysia
[5]Faculty of Electrical Engineering Technology, Universiti Teknikal Malaysia Melaka, Malaysia
[6]Department of Electrical Engineering, Universitas Ahmad Dahlan, Indonesia

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ABSTRACT

Power system stability is the capability of power systems to maintain load magnitude within specified limits under steady state conditions in electrical power transmission. In modern days, the electrical power systems have grown in terms of complexity due to increasing interconnected power line exchange. For that, an inherent of controllers were essential to correct the deviation in the presence of external disturbances. This paper hence aims to review the basic concepts of power system stability in load frequency control. Various control techniques were analyzed and presented. Power system stability can be classified in terms of method to improve power system stability, which are rotor angle stability, frequency stability and voltage stability. It is found that each method has different purpose and focus on solving different types of problem occurred. It is hoped that this study can contribute to clarify the different types of power system stability in terms of where it occurs, and which is the best method based on different situation.

Corresponding Author:

Muhammad Nizam Kamarudin
Faculty of Electrical Engineering
Universiti Teknikal Malaysia Melaka
Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
Email: nizamkamarudin@utem.edu.my

1. INTRODUCTION

Stability in the interconnected power system is known as its capability to return to stable operation after perturbed by disturbances. In contrast, instability in power system indicates the condition of losing synchronism or falling out of step. Stability consideration is recognized as an essential part in power systems that continually growing and extending over vast geographical regions. As such, preserving stability region in power system operation and maintaining the synchronism between various parts in power system has becoming a crucial tasks to engineers [1-3].

Successful operation of interconnected power systems requires the matching of total generation with total load demand and also associate with system losses. Changes in power system operating point may deviates the nominal frequency. Successful operation of interconnected power system requires the matching of total generation with total load demand as well as the ability to tolerate to associated system losses. Hence, interconnected power system with poor stability condition may experience deviations in nominal system frequency that yield to catastrophic effects [1].

One of the important elements in power system stability is load frequency control (LFC) [3-4]. It is important to maintain the frequency in a desirable level after disturbance occurs. In recent years, there are several types of control that were introduced [3-10]. However, research has consistently shown that previous control methods are lack of robustness towards the uncertainty's parameter. Therefore, objective of this paper is to review a few conventional methods and presenting the research gaps and new research directions in LFC.

2. CONCEPTS OF POWER SYSTEM STABILTY

Stability in power system defines the ability of the system to regain a state of operating equilibrium after being injected by disturbances. In power system, all variables are bounded. As such, the entire system remains intact [1, 2] and interconnected. The type of disturbances are faults, load changes, generator outrage, and line outrage or voltage collapse. Plus, the source of disturbances can be the combination of all. As depicted in Figure 1, power system stability can be classified into rotor angle, voltage stability and frequency stability [2]. Each of these three stabilities can be further classified into large disturbance or small disturbance, as well as short term or long term stability issues.

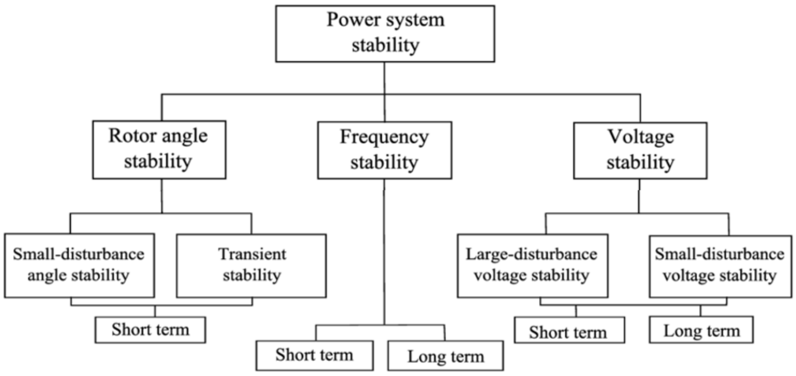

Figure 1. Classification of power system stability

2.1. Rotor angle stability

Rotor angle stability is the ability of the system to remain in synchronized state when subjected to a disturbance. The rotor angle of a generator depends on the equilibrium between the mechanical torque and the electromagnetic torque. The mechanical torque is produced through the input of the mechanical power that is exerted by prime mover. Whereas the electromagnetic torque produces generator electrical power. While in synchronizing state, all generators' electromagnetic torque is exactly equal to the mechanical torque in the opposite direction. If the balance between mechanical torque and electromagnetic is disturbed by any perturbation, the rotor angle will oscillate. Rotor angle stability can be classified into small disturbance angle stability and large disturbance angle stability.

2.2. Voltage stability

Voltage stability is the ability of the system to maintain steady state voltages at all the system buses when subjected to a disturbance. Larger disturbances produce a large disturbance voltage stability. While less significant disturbance produces a small disturbance voltage stability. Compared to the rotor angle stability, the voltage stability can also be classified as a long term and short-term phenomenon. In case of voltage fluctuation occurrence due to fast switching device like the induction motor, power electronic drive, or HVDC, the time frame for understanding the stability is in the range of 10-20 seconds. For that, the issue can be considered as short-term phenomenon [2]. However, if the voltage variations are due to slow changes in load, over loading of line, as well as generators hitting reactive power limits or tap changing transformers, then the time frame for voltage stability can be longer. The history of recorded time frame is around 1 minute to several minutes (more that 1 minute).

2.3. Frequency stability

The ability of the power system to maintain steady frequency due to severe disturbance between generation and load is called a frequency stability. The performance can be measured by the capability of the system to restore equilibrium between system generation and load, with minimum loss of load. Frequency instability may cause frequency swings that lead to tripping of generation units or load.

3. TECHNICAL WORKS ON LOAD FREQUENCY CONTROL

Power system frequency control is very well known as LFC. LFC has been one of the functions of automatic generation control (AGC) and nowadays becomes one of the important control subjects for research. The reliability and stability of the power system are mainly depending upon frequency deviation from its nominal value [3]. The objectives of LFC are [4]: to maintain constant frequency throughout the system, to preserve the tie line power at a scheduled level irrespective of load changes in any area, to diminish area control error (ACE), and to improve transient performance. The AGC schemes have evolved over the past six decades. This is based on the tie line load bias control concept. There are two variables of interest namely, frequency and tie line power exchanges. Their variations are weighted together by a linear combination to a single variable called ACE. The continuous advancement in the design and implementation of AGC strategies has enabled power engineers to deal with AGC problem more efficiently and effectively [5, 6]. Several investigations have been reported in the past applicable to the load frequency control in the interconnected multi area power system. Some of control strategies have been proposed in the literature based on classical linear control [7, 8]. Somehow, because of the existing qualities of the changing loads, the working purpose of the power system changes consistently during a daily cycle. Thus, a fixed controller may no longer be suitable in all connected variable structure control [9-12] to ensure the insensitivity to the system parameters change.

The first paper in the field of automatic generation control was introduced in 1954 by Concordia [13]. Up to date, appreciable research work is done in the area of automatic generation control and load frequency control [13-15]. In the research, the smart load frequency control had been analyzed in the problem of two equal area hydro, thermal and hydro-thermal systems. The research showed that the frequency bias must be set equal to the frequency response characteristic in order to obtain minimum interaction between control areas. Elgerd and Fosha [14] proposed the megawatt-frequency (P-f) control problem which has been selected for critical examination. This problem is as old as the power systems technology itself. The revolutionary optimal control is a concept for automatic generation control regulator designs of interconnected power systems. Due to recent system breakdowns, interest in overall system stability has focused on this problematic area. Cohn [15] proposed a technique based on coordinated system wide correction based on inadvertent interchange and time error. It studied the static aspect of the net interchange tie line bias control strategy, particularly the considerations for deciding the frequency bias setting. Based on static analysis, for minimum interaction between controls areas, the frequency setting of control area should be matched to combine generation and load frequency response of the area. However, it remained silent regarding the magnitude of gain setting of the controller and the dynamic aspects.

The first attempt in the area of AGC has been proposed to control the frequency of a power system via the flywheel governor of the synchronous machine. This technique was subsequently found to be insufficient, and a supplementary control was included to the governor with the help of a signal directly proportional to the frequency integral plus its deviation. This scheme constitutes the classical approach to the AGC of power systems. Very early works in this important area of AGC have been carried out by Cohn *et al.* [16-20]. These works were based on tie-line bias control strategy. Quazza [21] on the other hand has discussed on non-interactive control considering the non-interaction between frequency and tie line powers control, where each control areas deals with its own load variations. The research with large signal dynamics of LFC systems were reported by Aggarwal and Bergseth [22]. Supplementary controllers were designed to regulate the ACEs to zero effectively. Later on, energy source dynamics were incorporated in AGC regulator design [23]. The standard definitions of the terms associated with the AGC of power systems were finalized in [24]. Following that, suggestions for dynamic modeling for LFC are discussed thoroughly in [25-27]. Based on the experiences with actual implementation of AGC schemes, modifications to the definition of ACE are suggested from time to time to cope with the changed power system environment [28-32]. Since many of the presently regulated markets are likely to evolve into a hybrid scheme, and some deregulated markets are already of this type (e.g., Norway), the effects of deregulation of the power industry on LFC have been addressed thoroughly in [33].

4. PERFORMANCE ANALYSIS ON PREVIOUS CONTROL STRATEGIES

A number of control techniques are being put forward by the researchers in their pioneer work to design LFC controller were based on classical proportional-integral-derivative (PID) control techniques, a linear quadratic regulator (LQR) based controlling techniques and linear matrix inequalities. Other than that, the LFC design were also based on soft computing or artificial intelligence (AI) techniques such as genetic algorithm, neural network, fuzzy logic, bacterial foraging optimization and sliding mode control, H_∞ and particles swarm based techniques. Vijay in [34] compared the performance between the bacterial foraging optimization (BFO) with genetic algorithm (GA) and particle swarm optimization (PSO). The novel of BFO is to tackle economic load dispatch (ELD) issue including valve point effects. The proposed algorithm has been tested with a testbed with three to thirteen generating units. The results showed that the proposed algorithm gave effective quality solutions for ELD problems and also revealed that the fuel costs are reduced. Meanwhile, Sabahil in [35] discussed the power system load frequency control by modification of the dynamic neural network (MDNN) controller in two-area power system for generating electricity with good quality. The controller has dynamic neurons in hidden layer and conventional neurons in other layers. The neural network emulator (NN-emulator) was used to identify the model simultaneously with control process to considering for the sensitivity in the system model. The neuron receives its input either from other neurons or from the neural sensors, and the weighted sum of these inputs constituted the argument of a fixed nonlinear activation function. The proposed controller had been used because the whole structure of power system have nonlinear dynamic and their operation points may change, which therefore the adaptive controller should be used and has demonstrated that the system gave good results when compared to the conventional neural network (CNN).

Furthermore, Kumar in [36] observed that the parameter of PID controller and bias coefficient for load frequency control (LFC) are designed using a new approach. In the proposed technique, the power system instabilities and nonlinear impediments of governors and turbines, i.e. valve speed limit (VSL) and generation rate constraint (GRC), are considered in the design. Variations of uncertainties and nonlinear limitations are considered to be between -40% and +40% of nominal qualities with 5% step. The PID controller tuned based on GA was used to nullify the effect of frequency and tie line power deviations. On the other hand, Sreedhar Allu in [37] emphasized the advantages of fractional order PID (FOPID) controller over conventional PID with root locus tuning in single area power systems. In [37], the concept was extended to a multi area thermal power system with non-linearity of GRC. To reach the research outcomes, FOPID controller was tuned by using bacterial foraging optimization algorithm (BFOA) that employ an integral time multiplied absolute error (ITAE) as an objective function. The robustness of proposed controller was proved by using a transport delay (TD). Padhan in [38] observed the tuning technique utilized to model PID load frequency controller implied for power systems alongside transfer based acknowledgment strategy was considered for estimation of flow of the power system. Strength examinations on dependability and in addition execution were given in connection to vulnerabilities in parameters of the plant and it was seen that all in all the system remains asymptotically relentless for every encased uncertainty not withstanding motions in the system.

Saikia in [39], witnessed that the extra degree-of freedom drops the effect of undesirable posts of the unsettling influence, enhancing the aggravation lessening execution of system having shut circle. Firefly algorithm (FA) was utilized as part of frequency control in combined cycle gas turbine (CCGT) plant for controller increase enhancement in the paper. Likewise, performance of customary controller parameters in integral (I), proportional-integral (PI), PID and in additional integral derivative (ID) were thoroughly analyzed. Meanwhile in [40], Wen Tan brought into an idea of PID tuning system subject to two-level flexibilities for LFC in power system. Likewise time domain in addition to robustness of important PID controller was related to two regulation limitations and additionally, its strength was examined. The results indicate changes in damping of power system. In [41], El-Sherbiny investigated an application of the fuzzy logic technique while designing the load frequency control system to damp the frequency and tie line power oscillations due to different load disturbance. The proposed fuzzy logic frequency controller, called a two layered fuzzy controller having two layers. While the second counterpart, is called feedback fuzzy logic controller. Recently, PID controller was widely used in various applications. Lokanatha [42] proposed a particle swarm optimization PID (PSO-PID) controller to compare with the classical controller. The performance of the PSO tuned PIOD controller in two area power system is proven. The error has been reduced while the dynamic response of the system has been significantly improved. As compared to conventional PI and PID controller under different load conditions, the performance and robustness of the proposed PSO-PID is acceptable.

In [43] Ali observed that an application of the novel artificial intelligent search technique to optimize three-term PID parameters for a nonlinear load frequency controller. In this word, two area non reheat thermal system was considered. To minimize the time domain objective function, a technique called a bacterial foraging optimization algorithm (BFOA) is uyilized while searching for optimal controller parameters. Ahsan in [44] conduct a comparative studies between a two-term PI controller and fuzzy logic for interconnected power system with load frenquency controller. The outcomes showed that fuzzy logic improve the transient performance as compared to conventional PI controller.

Rerkpreedapong in [45] proposed two decentralized robust load frequency control using genetic algorithms and linear matrix inequalities. The first one was based on H Infinity (H_∞) control design and the second one was based on genetic algorithm (GA) optimization. Both were used to tune the control parameters of the PI controller called genetic algorithm linear matrix inequalities (GALMI). Both proposed controllers were tested on a three area power system with three scenarios of load disturbances to demonstrate the robustness of their performances. The simulation results showed that the responses of GALMI tuned PI load frequency controllers were almost the same as those of the robust H_∞ controllers, which have effective control performance and robustness against possible disturbances. Pandey in [46] presented a novel LQR control approach along with the doubly fed induction generator (DFIG) of wind energy. The design controller was used to extract the kinetic energy of DFIG to control the interconnected power system. As a result, the proposed controller minimized the area of control error and enhanced the time response of both the tie line and frequency deviation. To achieve a stable system along with the improved time response, the LQR was inserted in the feedback element.

In [47], Kumari and Jha presents the scientific demonstration of two area system with interconnected warm power system in state space. The control system procedure is known as LQR alongside with relative indispensable PI controller. The system frequency reaction upgrade was the aim in this paper. The PI controller increment were taken as the ideal state-input picks up alongside other state variables of the system for AGC. The warm turbine for warm area have been considered for the system. At the point when the load on the system changes, the variety in the frequency was ought to be least for a framework with legitimately designed automatic area control. To upgrade the frequency reaction against the heap changes, LQR was tuned by PSO. Mi in [48] proposed an LFC strategy based on sliding mode control (SMC). The research focuses on uncertain hybrid power system in order to reduce the frequency deviation caused by the unmatched parameter uncertainties such as the renewable source and different load disturbance. The proposed controller was reconstructed based on the designed disturbance observer (DOB). The outcome shows improvement in dynamic performance and suppress the chattering that results in stable and faster response. The disturbance observer was also designed to improve the accuracy of the sliding mode load frequency controller.

In the meantime, Rani in [49] proposed a genetic algorithm based PID (GAPID) controller for a multi-area AGC scheme. The GAPID was tuned by minimizing the fitness function to get the optimal parameter of PID controller. Integral of the square of the area control error (ISACE) have been utilized to select the fitness function for GA. The population size is 50 is considered adequate for GA to obtain the optimal values of PID controller. The designed optimal AGC schemes were implemented to cater 1% load perturbation in one of the power system areas. The AGC using GAPID controller produces 11 second settling time. Finally, Karun [50] proposed a Fuzzy Logic based control to design a bidirectional power charging controller for electric vehicles (EV). The proposed design aims to stabilize frequency fluctuation in the system with photovoltaic (PV) systems. The grip operator controls the charging power to the desired value by sending signal to all EVs. The outcomes show that the system robust towards load changes and guarantee stability of the EV against PV power generations.

5. CONCLUSION

Power stability can be classified into three parts. These three main parts are rotor angle, voltage stability and frequency stability. Voltage collapse at a bus trigger a large excursion in frequency and rotor angle. Correspondingly, large frequency deviations cause large changes in the magnitude of voltage. Power system requires normal and stable operation at rated operating condition to preserve stability. It was noted in the paper, lists of contributions existed for controlling and stabilizing the system frequency either in a single or multi area interconnected power system. Different control approaches were reviewed to study the behavior of the system and the performances under different conditions. It is hoped that this review opens new avenue in power system stability research growth.

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